Title	Reconstruction of three-dimensional moving paths of green turtles by means of magneto resistive data loggers
Author(s)	Yasuda, Tohya; Arai, Nobuaki; Tanaka, Hideji; Kittiwattanawong, Kongkiat; Sakamoto, Wataru; Masuda, Haruhiko; Klom-In, Winai
Citation	Proceedings on the 4th SEASTAR2000 Workshop (2000): 5-8
Issue Date	2000
URL	http://hdl.handle.net/2433/44121
Right	
Type	Conference Paper
Textversion	publisher

Reconstruction of three-dimensional moving paths of green turtles by means of magneto resistive data loggers

TOHYA YASUDA[1], NOBUAKI ARAI[1], HIDEJI TANAKA[1], KONGKIAT KITTIWATTANAWONG[2], WATARU SAKAMOTO[3], HARUHIKO MASUDA[4] and WINAI KLOM-IN[5]

[1]*Graduate School of Informatics, Kyoto University Kyoto 606-8501, JAPAN*
Email: tohya@bre.soc.i.kyoto-u.ac.jp
[2]*Phuket Marine Biological Center, P.O. Phuket 83000,Thailand*
[3]*Faculty of Agriculture, Kinki University, 631-8505 Nara, Japan*
[4]*Alec Electronics Co., Ltd. 7-2-3 Ibukidai-Higashimachi, Nishiki, Kobe, 651-2242 Japan*
[5] *Naval Special Warfare Group, Royal Thai Navy, P.O. Box 21 Sattahip,Cholburi 20180. Thailand*

ABSTRACT

We reconstructed the spatial and temporal diving behavior of a green turtle using cutting edge data loggers. The reconstruction of three-dimensional moving paths of the green turtle has been one of important themes in SEASTAR2000 project. To reconstruct the three-dimensional moving paths of green turtles, we developed the magneto-resistive acceleration data logger (MR logger) to record magnetic field and acceleration. Field experiments were conducted in Huyong Island, Thailand. The MR logger and Speed/Depth/Temperature data logger (PDT logger) were attached on a carapace of a female green turtle nested on the beach. Sampling frequencies of the data loggers were 10 Hz for the MR logger and 1 Hz for the PDT logger. The 3-D moving paths of the green turtle were reconstructed by her horizontal body directions, vertical tilt angles and swimming speeds. The horizontal body directions of the green turtle were calculated from the surging and swaying magnetic field. The vertical tilt angles of the green turtle were calculated from the surging acceleration.

KEYWORDS: **green turtle, diving behavior, three-dimension, data logger**

INTRODUCTION

The green turtle (*Chelonia mydas*), is listed as an endangered species on the IUCN red list, and has been recognized as species for conservation in many countries. Traditionally, to conserve the turtles, many studies have focused on the investigation on the beach. The biotelemetry contributed to these studies undoubtedly. For example, long or short distance migrations between reproductive sites and feeding sites were found using satellite telemetry in their habitats (Hays *et al.*, 2001; Hatase *et al.*, 2002). In the studies using data loggers, Eckert *et al.* (1989) reported that leather back turtle (*Dermochelys coreacea*) has dived to more than 1,000 m. Recently, Minamikawa *et al.* (2000) reported that the lung air was used to achieve neutral buoyancy in loggerhead turtles (*Caretta caretta*). Although spatial-temporal analysis of the behavior of the sea turtles is very important for better understanding of the species, a three-dimensional diving path for the sea turtles is still unknown. Major reason is that the measurement technique, which can record spatiotemporal data, has not been developed. Sea turtle researchers who used data loggers depended on time-depth series data logger (Eckert *et al.*, 1989; Minamikawa *et al.*, 2000). But, time-depth-series data alone cannot give a real moving track of aquatic animal. In this paper, we introduce the new data logger to record the magnetic field and acceleration. We tried to calculate body direction and tilt angle of the green turtles through this data logger and to illustrate a three-dimensional diving path of the turtle.

MATERIALS AND METHODS

Data loggers

To measure a three-dimensional diving path of green turtles, we developed two types of data loggers (Fig. 1). Magneto-Resistive (MR) logger has two types of sensors, MR sensor and acceleration sensor. The MR sensor is to record a surging and a swaying magnetic field, whereas an acceleration sensor records a surging acceleration and a swaying acceleration (Fig. 2). The MR logger has a memory of 64 MB (5,760,000 data) and is programmed to record the data at an interval ranging from 5 ms to 1 min. The range of measurement and resolution were ±2 Gauss and ±1 % FS (magnetic field) and ± 98 m/s^{-2} and ± 0.2 % FS (acceleration), respectively. The instrument was 40.8 mm in diameter, 300 mm in length, and weighed 320 g in water.

CCD logger has a color CMOS sensor to record 28,000 pixels photograph. The sampling interval is four photographs per 1 hour. The logger has a memory of 1 MB (80 photographs). A light sensor equipped with the

CCD logger helped in taking photos in the daytime because the logger does not have a flash unit. The instrument was 92 mm in length, 40 mm in width, less than 28 mm in height, and weighed 155 g in water. Swimming speed and depth were monitored using speed-depth-temperature (PDT) logger (UWE-200PDT; 13 g in water, 20 mm in diameter, 90 mm in length, Little Leonardo Co., Ltd), simultaneously.

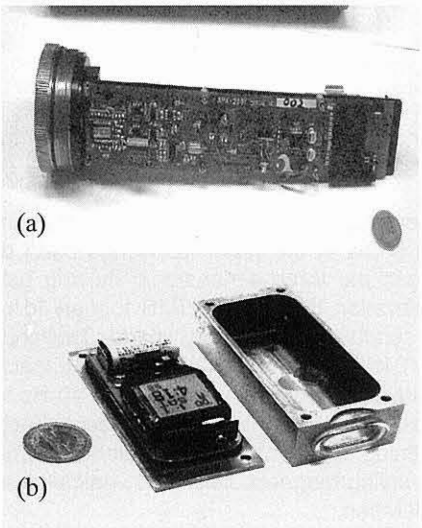

Fig.1. Photos of a MR logger and a CCD logger. The photo (a) is MR logger and the photo (b) is CCD logger.

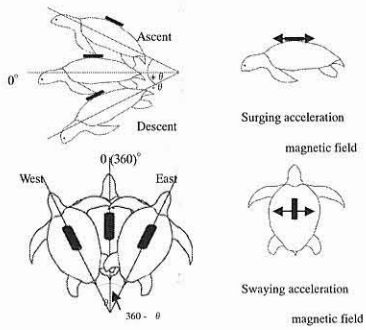

Fig.2. Schematic diagram showing the direction of surging and swaying geomagnetic and acceleration recorded by a data logger on the carapace of a green turtle (black bar). Data for surging acceleration were converted to tilt angles. Data for surging and swaying geomagnetic were converted to body directions.

Field experiments

Experiments were conducted on the nesting beach at the Huyong Island of Similan Islands (8.28°N, 97.38 °E) in the Andaman Sea from May 15 to May 31, 2003. The Huyong Island is a desert island. But it has a primal nesting beach of green turtles on the Similan Islands. The length of the nesting beach is approximately 800 m and the beach is protected by the Royal Thai Navy. All nesting turtles landed on the beach are identified by microchips inserted into their roots of both flippers and inconel tags. Generally, green turtles lay eggs several times on the same beach at approximately 2-week intervals during one breeding season. Therefore, if we attach the data loggers to a turtle at the first or second nesting, we can recover the data loggers from the turtle at next nesting.

Night patrol was conducted from 8:00 PM to 4:00 AM to find female green turtles landed on the beach for nesting. The data loggers were attached on the carapace of the nesting female green turtle (Curved carapace length 100.0 cm) after the turtle laid eggs. First we attached two wooden pedestals on the carapace of the turtle using epoxy resin. We used the pedestals to attach the MR logger parallel to body axis of the turtle, and the pedestals played a role as float. Second, the MR logger (sampling frequency 10 Hz) was attached on the pedestals using cable ties. The PDT logger (sampling frequency 1 Hz) was attached beside the MR logger using epoxy resin. The CCD logger was attached on the front of carapace of the turtle using epoxy resin. We retrieved the data loggers from the turtle when the turtle subsequently returned to the beach.

Body direction

Figure 3 shows normalized outputs of the MR sensor. The normalized outputs were ranging from -100 to 100. When the sensor was held horizontally and was rotated clockwise from the north direction, responses of the surging and swaying magnetic field recorded by the MR sensor showed the cosine (surging) and sine (swaying) functions. We calculated the horizontal body direction (θ_1) using this relationship between surging magnetic field (x) and swaying magnetic field (y) by following Equation 1.

$$\theta_1 = \begin{cases} 90 & (x = 0, y > 0) \\ 270 & (x = 0, y < 0) \\ 180 + \mathrm{atan}(y / x) * 180 / \pi & (x < 0) \\ \mathrm{atan}(y / x) * 180 / \pi & (x > 0, y > 0) \\ 360 + \mathrm{atan}(y / x) * 180 / \pi & (x > 0, y < 0) \end{cases} \quad (1)$$

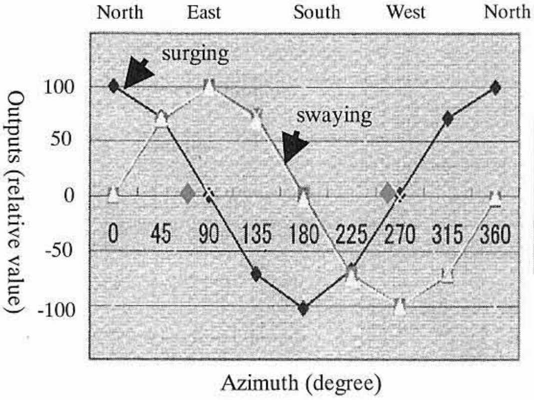

Fig.3. Normalized outputs of MR logger when the logger was held horizontally and rotated clockwise from the north.

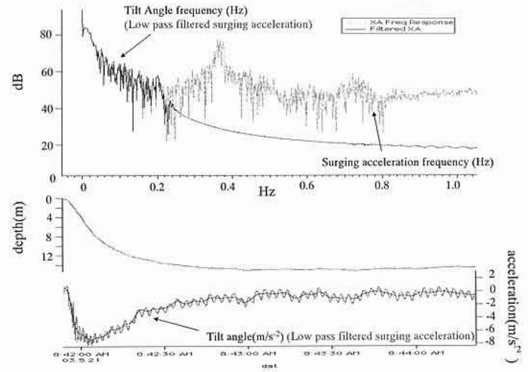

Fig.4. Frequency response and expanded time-series of surging accelerations of the turtle for a typical diving. The Upper graph shows frequency response of surging acceleration and lowpass filtered surging acceleration. The lower graph shows expanded time-series of depth, surging acceleration and lowpass filtered surging acceleration, which showed tilt angle of the turtle.

Tilt angle

The acceleration sensor along the body axis of an animal is affected by both forward movement s of an animal and gravity (Yoda *et al.*, 2001; Tanaka *et al.*, 2001). We found the peak at 0.36 Hz. This peak may indicate a flipper movement frequency of the turtle. Moreover, high frequency variations ranging from 0.2 Hz to 0.4 Hz recorded in the surging acceleration may indicate to be caused by the flipper movement for the turtle. These frequencies were filtered out using a 0.2 Hz low-pass filter (IFDL Version 3.1; WaveMatrics, Inc., USA; Tanaka *et al.*, 2001) to get the tilt angle (Fig. 4). When the animal is still or moving at constant speed, the gravity vector (g = 9.8 m/s2) will change in response to the tilt angle (Tanaka *et al.*, 2001). Therefore, we have calculated tilt angle (θ_2) of the turtle using low-pass filtered surging acceleration (A) as the following Equation 2

$$\theta_2 = \mathrm{asin}(A/g) \qquad (2)$$

We tried to attach the MR logger parallel to body axis of the turtle using the two wooden pedestals. However, it was difficult to put the MR logger exactly parallel to the body axis of the turtle. Therefore, it was necessary to correct an initial error of the tilt angle calculated from the surging accelerations. As described by Sato *et al.* (2003), initial error of the tilt angle can be corrected by the comparison between a dive profile measured by depth sensor and calculated dive profile by several adjustment tilt angle. Therefore, we corrected the initial error of the tilt angle by this method.

Horizontal moving paths

Horizontal moving paths of the turtle, which are longitudinal moving distance (d_1) and latitudinal moving distance (d_2), was calculated from the body direction (θ_1), tilt angle (θ_2) and swimming speed (v) by Equation 3 (longitudinal movement) and Equation 4 (latitudinal movement).

$$d_1 = v * \cos(\theta_2) * \cos(\theta_1) \qquad (3)$$
$$d_2 = v * \cos(\theta_2) * \sin(\theta_1) \qquad (4)$$

RESULTS AND DISCUSSION

We analyzed the data from May 21 to May 23, 2003. The turtle carried on with a continuous dive. The mean maximum depth of dives was 13.88 m. The mean duration of dives was 18.17 min. The mean rate of bottom time (bottom time per dive duration) was 0.35 % (n = 95).

The data presented in Figure 5 describe a typical dive of the turtle. Dive duration was 710 seconds. Maximum dive depth was 15.20 m. Mean swimming speed was 0.81 m per second. Figure 6 shows horizontal moving path and relationship between swimming direction and diving depth. The turtle descended northwestward and ascended southwestward during this dive. The turtle has maintained its direction relatively constant during this dive. Therefore, we illustrated the three-dimensional diving path of the turtle by direction and swimming speed data (Fig. 7). However, the illustrated moving path of the turtle may be affected by ocean current because the PDT logger measured a swimming speed using a propeller. Therefore, an estimated error that could affect the accuracy of the calculation of the turtle was accumulated in the moving path. Davis *et al.* (2001) and Mitani *et al.* (2003) adjusted the accumulation of the errors of the three-dimensional diving path of seals using "dead reckoning" methods. However, we cannot apply this method to adjust the accumulation of errors because a start position of dive of sea turtles differs from a goal position of the dive. To adjust the accumulation of errors of the diving track, it is very important to get positional information of diving turtle. Now we are developing the Argos transmitter equipped with GPS sensor for sea turtle study. So we will adjust the accumulation error of diving path of the turtle using GPS position in the near future.

Three-dimensional analysis by the MR logger will gratefully contribute to the studies on behavior of sea turtles. For example, we know that a sea turtle lay eggs on the beach and migrate between the fixed feeding area and fixed nesting area. However, the ability to find the nesting beach and feeding area is still unknown. A body direction of the turtle measured by the MR logger will contribute to elucidate this ability.

Traditionally, migration paths of sea turtles were studied using satellite telemetry (Hays *et al.*, 2001; Hays *et al.*, 2002; Hatase *et al.*, 2002). However, when detailed aspects of satellite tracking data are considered, such as speed of travel and small-scale movements of sea turtles, then location accuracy is likely to become an important issue (Hays *et al.*, 2001). In sea turtle study, a high proportion of locations may be of low quality because a signal from a transmitter uplinks to the satellite only when a turtle swim at sea surface. The MR logger tracking will become a solution for this problem. MR logger can track a migration path of the turtle continuously. The recording time of the MR loggers, however, are limited due to their battery. Therefore, our future plan is to track more detailed migration paths of turtles all through the inter-nesting intervals.

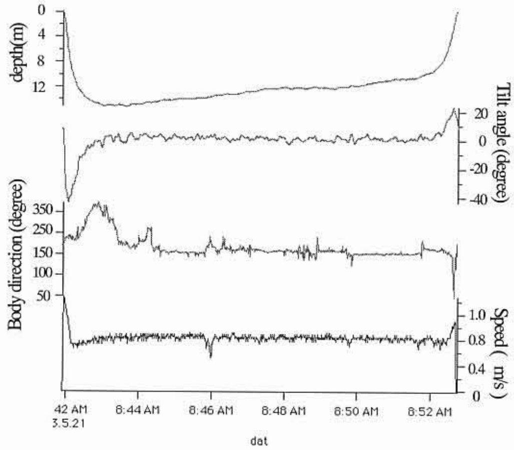

Fig.5. Expanded time-series of depth, tilt angle, body direction and swimming speed for typical 1 dive of the turtle.

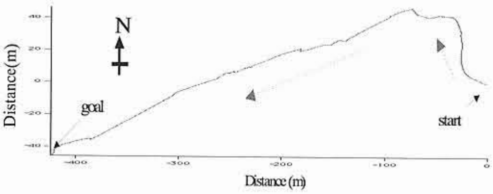

Fig.6. Horizontal moving path for typical 1 dive of the turtle.

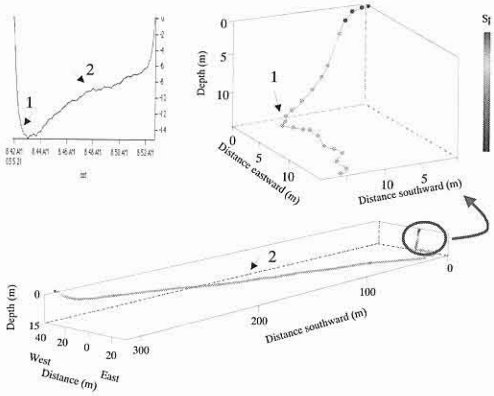

Fig .7. Three dimensional moving paths for typical transit dive of the turtle during inter-nesting interval.

ACKNOWLEDGEMENTS

We gratefully thank all members of Phuket Marine Biological Center and Royal Thai Navy who have supported the field experiments. We thank the National Reserch Council in Thailand. This study was partly supported by a Grant-in-Aid for Scientific Research (13375005, 12556032 and 14560149) and Information Research Center for Development of Knowledge Society Infrastructure, the Ministry of Education, Culture, Sports, Science and Technology. We thank three anonymous reviewers for their comments.

REFERENCES

Davis *et al.*, 2001. Three-dimensional movements and swimming activity of a northern elephant seal. *Comp Biochem Physiol A*. **129**. 759-770

Eckert S. A. *et al.*, 1989. Diving and foraging behavior of leatherback sea turtles (*Dermochelys Coriacea*). *Can. J. Zool.* **67**. 2834-2840.

Hatase, H. *et al.*, 2002. Size-related differences in feeding habitat use of adult female loggerhead turtles *Caretta caretta* around Japan determined by stable isotope analyses and satellite telemetry. *Mar. Ecol. Prog. Ser.* **233**. 273-281.

Hays, G. C. *et al.*, 2001. The implications of locations accuracy for the interpretation of satellite-tracking data. *Anim. Behav.* **61**. 1034-1040

Hays, G. C. *et al.*, 2002. Biphasal long-distance migration in green turtles. *Anim. Behav.* **64**. 895-898

Minamikawa, S. *et al.*, 2000. Maintain of neutral buoyancy by depth selection in the loggerhead turtle *Caretta caretta*. *J. Exp. Biol.* **203**. 2967-2985.

Mitani, Y. *et al.*, 2003. A method for reconstructing three-dimentional dive profiles of marine mammals using geomagnetic intensity data: results from two lactating Weddel seals. *Polar Biol.* **26**. 311-317

Sato, K. *et al.*, 2003. Factors affecting stroking patterns and body angle in diving Weddell seals under natural conditions. *J. Exp. Biol.* **206**. 000-000.

Tanaka, H. *et al.*, 2001. Swimming speeds and buoyancy compensation of migrating adult chum salmon *Oncorhynchus keta* revealed by speed/depth/acceleration data logger. *J. Exp. Biol.* **204**. 3895-3904.

Yoda, K. *et al.*, 2001. A new technique for monitoring the behavior of free-raging Adelie penguins. *J. Exp. Biol.* **204**. 685-690.